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WADC TECHNICAL REPORT 52-330

ON MULTILENS CAMERAS IN STEREOPHOTOGRAMMETRIC MAPPING

ROBERT ZURLINDEN
OHIO STATE UNIVERSITY RESEARCH FOUNDATION

OCTOBER 1952

WRIGHT AIR DEVELOPMENT CENTER

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NOTICES

WADC TECHNICAL REPORT 52-330 October 1952

ERRATA - May 1953

The following corrections are applicable to WADC Technical Report 52-330, "On Multilens Cameras in Stereophotogrammetric Mapping," dated October 1952:

Page 7

The line in parentheses immediately below the equations should read, "For condensed formulae see page 10."

Page 10

Last line of first paragraph should read, "we get the equations of page 7 of the paper."

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

WADC TECHNICAL REPORT 52-330

ON MULTILENS CAMERAS IN STEREOPHOTOGRAMMETRIC MAPPING

Robert Zurlinden
Ohio State University Research Foundation

October 1952

Photographic Reconnaissance Laboratory
Contract No. AF18(600)-90
RDO 683-44
RDO 683-58

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

FOREWORD

This report was prepared by the Mapping and Charting Research Laboratory of the Ohio State University Research Foundation under USAF Contract AF18(600) -90. The contract is administered by the Mapping and Charting Branch of the Photographic Reconnaissance Laboratory, Directorate of Laboratories, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio. Mr Fred J. Baty is Project Engineer on the project applicable to the subject of this report.

Research and Development Order Nos. R 683-44, "Research in Photogrammetry and Geodesy for Aeronautical Charting", and R 683-58, "Aeronautical Charting Systems", are applicable to this report.

This report was originally initiated at the Ohio State University Research Foundation as OSURF Technical Paper No. 166.

ABSTRACT

The four principal arguments in favor of the use of multi-lens cameras, and the four strongest drawbacks to such use are discussed. These advantages and disadvantages are critically evaluated in the individual cases of two, three, four, five, seven, and nine lens cameras.

The general conclusion is that the four-lens camera is the one multi-lens camera worth future consideration.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

E.B. Woodford
for DELWIN B. AVERY
Colonel, USAF
Chief, Photo Reconnaissance Lab.
Directorate of Laboratories.

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INTRODUCTION

This is a short introductory statement on the future possibilities of multiple-lens cameras. It should be made clear at the outset that the author does not necessarily advocate the use of these in stereo-photogrammetric mapping.

The conclusion reached in the paper is that the four lens camera is the multiple lens combination that offers most promise of successful application in the photogrammetrical process, at least if the latter involves spatial traversing.

ON MULTI-LENS CAMERAS IN STEREOPHOTOGRAMMETRIC MAPPING

Proposals for utilizing cameras with two, three, four, five, seven, and nine lenses have been frequent. Many multiple lens cameras have been constructed and used. These have had, in special cases, extended use, but their superiority over single lens cameras has never been successfully demonstrated and they have never become generally popular.

The reasons given for employing multi-lens cameras are generally among the following:

(1) They permit a wider spacing of flight lines, thus reducing the amount of flying;

(2) They permit a reduction in the necessary ground control, and enable the geometry of an aerial traverse to be strengthened by means of better conditioned intersections;

(3) They reduce the total amount of office adjustment work, by making the number of composite photographs smaller than would be the corresponding number of single photographs;

(4) By using lenses of smaller angular field computed with as much care as wide-angle lenses, they improve the definition and greatly increase the general and marginal illumination of the photographs.

Point (4), while seldom stressed in publications, is important in the opinion of the author. The advantage is that under certain circumstances flying may be much higher than with single lens cameras while getting equally good definition, and hence a considerable economy may be realized.

To offset these often extremely desirable advantages one or more of the following drawbacks may exist.

(a) Higher investment in camera and accesssories,

(b) Smaller accuracy of results and smaller wealth of descriptive information, due to bad incidence angles of rays with respect to the ground along the edges of the photograph,

(c) Reduced accuracy of results due to the composite relationship between the photographs taken from the same exposure station,

(d) Additional work resulting from the above composite relationship.

The reasons for the little success of former attempts can always easily be traced back to difficulties of the kinds just listed.

Let us now try to evaluate again the real importance of these drawbacks from the standpoint of the needs and possibilities of the future.

First of all, we can probably dispose of point (c) as no longer true, or at least no longer necessarily true. A calibration device and method for correcting systematic errors has been conceived by the author which, when developed, will make it unnecessary to adjust the component cameras to a rigorous geometrical scheme. This means, of course, a complete change of outlook.

Let us now look at point (a). A high investment, indeed, would have to be contemplated if the old way of approach to the accurate combination of the component cameras should still prevail, and if such devices as prisms or mirrors, rectifying apparatus, etc., should still be needed. But what has been said about point (c), and what the subsequent treatment of points (b) and (d) will teach us, leading us to eliminate all solutions with more than four lenses as well as any photographic transformation, frees us of any fears about the necessary investment.

And now to point (b). Experience has told again and again how useless it is to take pictures covering a very wide field, for these give a lot of trouble because of the bad "insight" into the details of the ground. The advantages claimed from angular fields extending over more than 120° diagonally in any direction prove to be purely fallacious. Sometimes, however, the idea underlying such designs is to include the horizon in the pictures, for purposes of external orientation. This, again, ought to be of little value for the future because it can be confidently expected that really rational ways of performing spatial traversing quickly, economically, very accurately and reliably over wide stretches of country will sooner or later be available. With such weapons in hand, it would be absurd to rely any longer on such fanciful elements as horizon lines, perfectly clear, dimly perceived or quite blurred according to the meteorological conditions of the moment. This eliminates too the idea of combining three cameras on a line, at least for the mapping purposes here considered.

Point (d) remains to be examined critically. Again we see what little good can be expected from cameras with as many as five, seven, or nine lenses, as these involve much supplementary work in rectifying, bringing to scale, etc., transformations which we discard at any rate because of the highly deplorable loss of definition they imply.

So we have found very strong objections against cameras with three, or then more than four lenses. There remains only to be seen whether two or four lenses have the highest chances of salvation in the general rout of multi-lens cameras.

Roughly speaking, this question is solved by first making a choice between single-lens cameras giving:

Fig. (α) Rectangular photographs with sides in proportion 1:2 (1 in direction of strip),

Fig. (β) Square photographs with sides equal to $\sqrt{5/2}$

Fig. (γ) Rectangular photographs with sides in proportion 2:1 (2 in direction of strip).

These cameras have all the same diagonal length and consequently the same maximum aberrations. This choice having been made, its conclusions can then be extended to the somewhat different conditions of two and four lens cameras.

A well-known advantage of the square size is to give the largest area of photograph for given aberrations in the corners. This, however, would not mean much if the experiences of practically all instrument builders had not also shown the superiority of square photographs from the fundamental point of view of precision of aerial traversing. A detailed study of this question, from the theoretical side, would be interesting. It will not be attempted here. Another way of approach will be given instead.

For this, a detour must be made here, in order to show facts little or not at all mentioned elsewhere in the photogrammetric literature; facts, however, which are of great help didactically.

What happens in the relative adjustment of a pair of photographs is easy to explain mathematically. However, there does not seem to exist an intuitive visual understanding of the geometry involved. How highly desirable this would be!

Actually, it is not easy to find one if the relative orientation of "independent pairs" is considered. But, if on the contrary we look at the much more important case of "dependent pairs" -- the case which dominates the fundamental problem of traversing -- it is different.

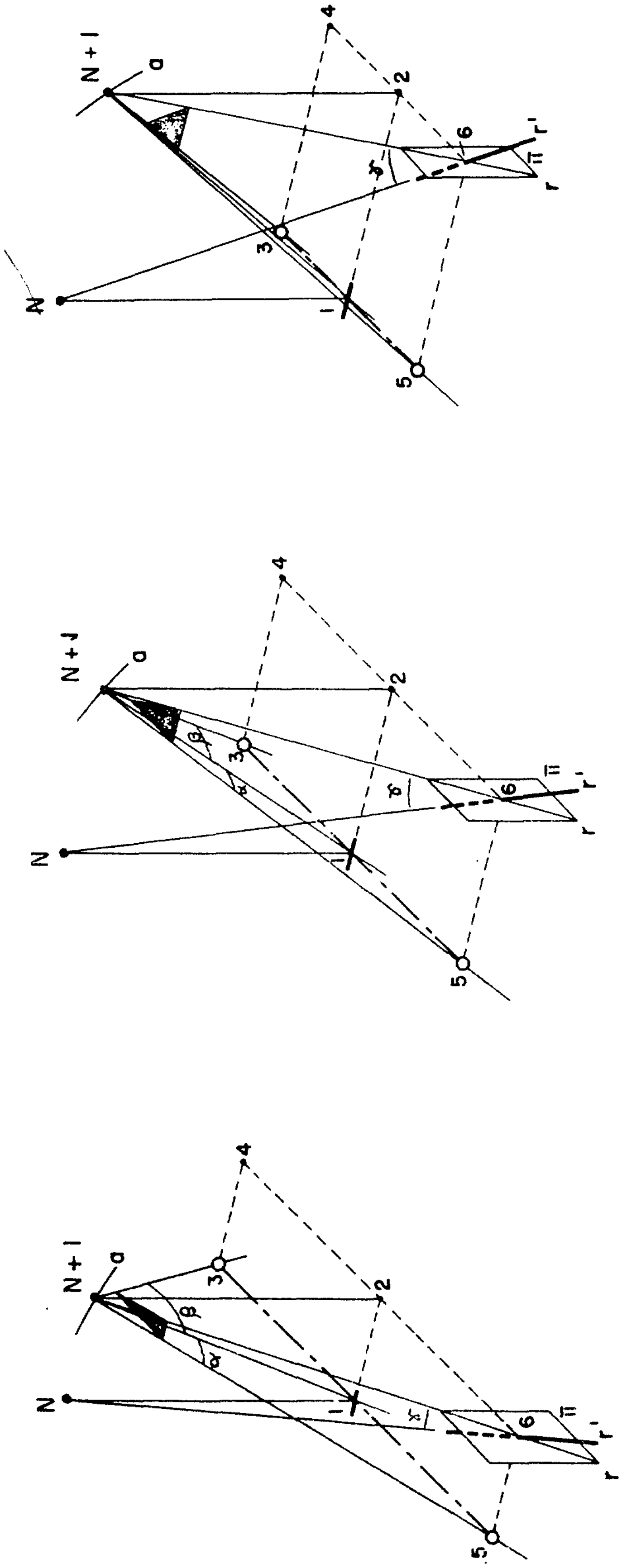

Fig. (δ)

Fig. (β)

Fig. (α)

FIGURE I

Let us assume first that the country is flat, and that only the classical six points (points 1, 2, . . . 6) are to be used as shown in Figure 1. Then one, three, five are points of known coordinates, determined after the preceding pair has been adjusted, and may be used immediately for spatial resection. This implies, ipso facto, the elimination of transverse parallax in these points. Points two, four, six are unknown in position and on these the transverse parallax procedure of relative orientation may be used.

It is easy to see now that three and five, together with the Y coordinate of one, allow of a Pothenot (angles α and β), hinged on the axis three - five, as giving a first determination of the point $(N + 1)$. Accordingly, this point has to lie on the arc a and nowhere else. Now let us take point six. The ray r, rigidly bound to the three Pothenot rays, describes in first approximation a plane π when the plane of the Pothenot rotates around its hinge three - five. This plane π intersects the known ray r' (under a certain angle γ) in six. If we stop the rotation of the trihedral α β r at the moment when r goes through six, relative orientation, as well as absolute orientation, is achieved without supernumerary determinations. Six elements are used (two in three, two in five, one in one, and one in six) for the determination of the six parameters describing the position and orientation of exposure point $(N + 1)$.

The same can be done again, using point four instead of six. This alternative, and taking into account the X coordinate in one and the intersection of rays in two, gives several checks which provide indispensable aids when the normal determination is weak.

And now, we see that it is easy to be freed from the assumptions of flat ground and only six points regularly distributed. What happens using points of arbitrary distribution, as in hilly and mountainous country of any form or when a lake or river or seashore interferes in the symetrical choice of points, can be followed, geometrically, in a few minutes, where the numerical analysis gives, after toilsome computations, only a maze of confusing figures.

It shows clearly, for instance, how it happens that the fundamental process in the above outlined procedure for spatial traversing, namely the determination of station $(N + 1)$, is free from ambiguity no matter what may be the configuration of the ground. As another example, it also reveals the well known fact that the famous "critical cylinder" is not in any way critical when dealing with dependent pairs of photographs. Of course this does not mean that mathematical analysis of orientation is not absolutely necessary. Nevertheless, the experience of the author, since he first used this way of reasoning, is that a quick, easy, and visual way of approaching practical problems of this kind is of considerable help.

Returning to the problem of evaluating the respective virtues of photographs of the (α), (β) or (γ) types: The figures now show clearly what is at issue. (α) gives a strong Pothenot, but weak X tilt determination, not only because of the small angle γ but because of the short radius five - six. The propagation of height errors is obviously bad. (γ), on the other hand, gives a weak Pothenot. The Y tilt determination is weakened, but still worse is the fact that the determination of length 1 - (N + 1) is weakened. This is the scale-transmitting length and is just the element that practical experience has always shown to be the weakest link in spatial traversing.

Thus this investigation easily confirms the superiority of square pictures. And because four lens photographs have approximately a square format, it also confirms the superiority of four lens photographs over any kind of two lens photographs. Furthermore, although the law of equivalence of aberrations appears differently, investigation of the nature of the difference shows that what applies to single photographs applies a fortiori for double and quadruple. So it can be concluded that the four lens camera, of all the multiple lens units, is alone in having potential possibilities, especially in spatial traversing.

Let us now consider closely all the main aspects of the use of four lens cameras. For this, we consider successively how far the goals initially listed under (1), (2), (3), and (4) can actually be reached.

(1): The four lens camera allows the strip width to be doubled and consequently the cutting down of the flying time by 50 %. (The gain in definition may also bring a substantial cut).

(2): The four lens camera permits a maximum reduction of ground control, with excellent balance between height and planimetry accuracy. It is indeed ideal in this respect.

(3): Here, care is necessary in appreciating the potentialities of the four lens camera. A favorable circumstance is that the original photographs can be used for plotting, without any transformation onto a common plane, provided the plotter allows of tilted convergent pictures being used. Interesting is the fact that if one should nevertheless choose to rectify the photographs first, this could be done independently for the four unit images, thus eliminating the notorious problem of getting clean joins (no gaps - no overlap), which has been the nightmare of people who introduced the nine and seven lens cameras. Unit photographs of one group just match unit photographs of the conjugate group for constituting adequate independent pairs, though the general overlap of the composite pictures must of course be rather generous. The question of whether this or that type of plotter already in existence is capable of plotting such pairs is of little interest here, as the discussion relates to the future when plotters can be made just what they ought to be.

Concerning traversing, here the assumption of having the composite photographs first transformed computationally to a common plane can hardly be avoided, though we can dispense with any photographic rectification. Numerical rectification is necessary because it is just the consistency of the four images obtained at the same instant which allows of so much economy. However, things are not bad if we consider that in traversing we use only isolated points in the pictures, instead of continuous lines as in plotting, for it happens that the formulae for numerical rectification, point after point, are extremely simple; at least if the traversing computer permits the introduction of a variable principal distance. These formulae are of the following form:

$$X_n = (A + \delta') X_1 + (B + \delta') Y_1 - (C - \delta'') Z_1$$

$$Y_n = (B + \delta') X_1 + (A + \delta') Y_1 - (C - \delta'') Z_1$$

$$Z_n = C (X_1 + Y_1) + (A + B) Z_1$$

(For condensed formulae see page eleven.)

where X_1, Y_1, $Z_1 = f$ are the unit photographic coordinates of a point, and X_n, Y_n, Z_n the resulting coordinates on the fictitious composite photograph. A, B, and C are constant coefficients and δ' and δ'' are very small correcting terms for compensating approximately the eccentricity of the four lenses. (They can be dropped if the lenses are close together or if not very accurate work is desired). δ' and δ'' are constant for a given mean flying height. Thus, taking all the circumstances into account, it is pretty certain that a substantial reduction of total office work can be reached with a four lens camera notwithstanding the slightly more elaborate procedure required.

(4): This fundamental possibility applies to any type of multi-lens camera. It is not difficult, however, to imagine circumstances in which the use of a four lens camera of no wider total angular field than a Metrogon single lens camera may find full technical and economical justification in spite of the few remaining drawbacks. It might have unequaled quality of image and perhaps such good illumination as to permit very short exposures, thereby reducing the effects of displacement and the so often troublesome rotatory vibration.

And so we reach the rather surprising general conclusion that the most despised type of multi-lens camera, the quadruple camera, the only one which has never found extensive practical use anywhere, is just the one which is still worth consideration in the future.

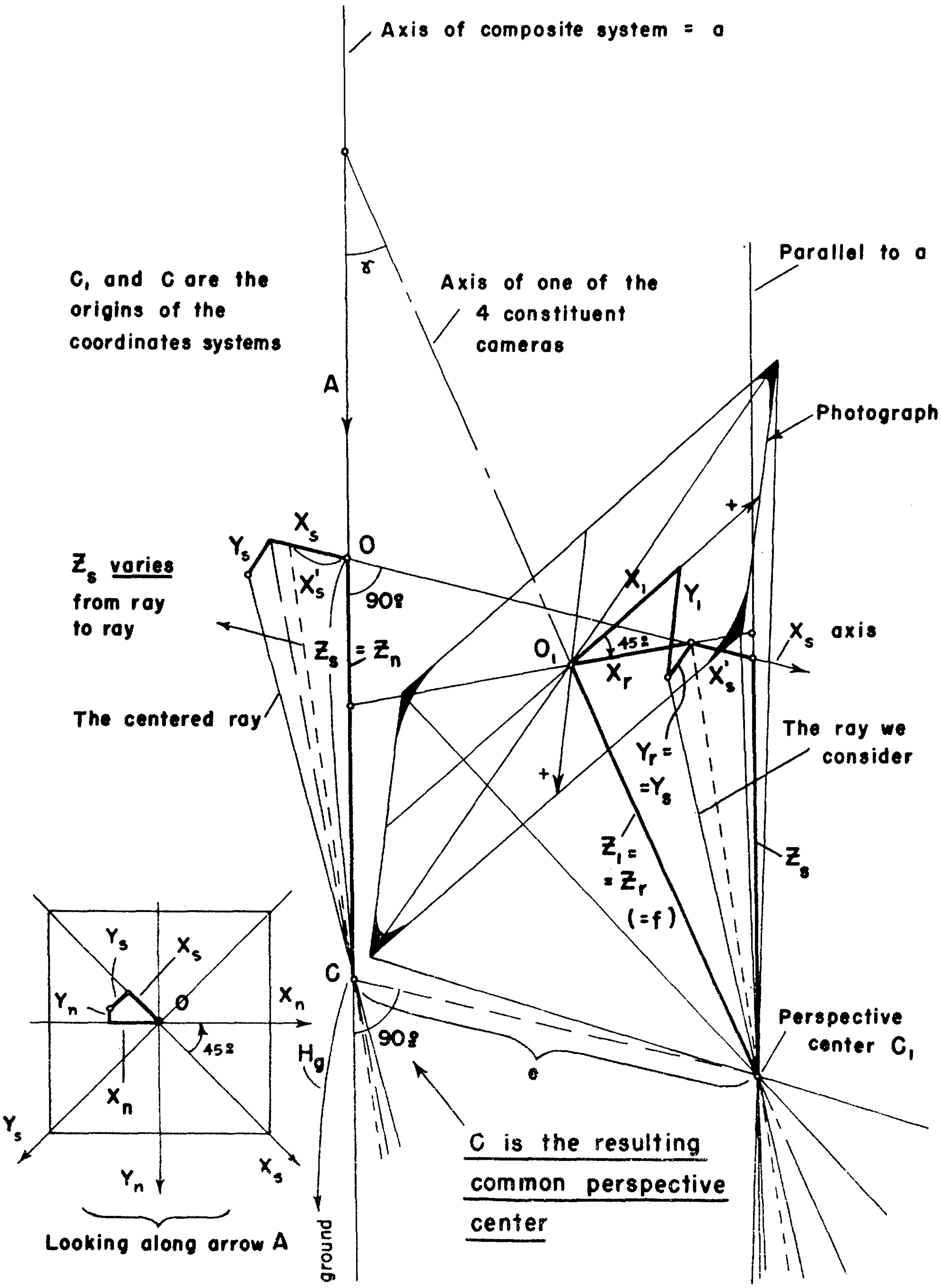
Axis of composite system = a
Parallel to a
C, and C are the origins of the coordinates systems
Axis of one of the 4 constituent cameras
A
Photograph
X_s
Y_s
O
Z_s varies from ray to ray
X'_s
90º
Z_s = Z_n
X_1
Y_1
O_1
45º
X_s axis
X_r
X'_s
The centered ray
The ray we consider
Y_r = = Y_s
Z_1 = = Z_r (= f)
Z_s
C
90º
H_g
e
Perspective center C_1
C is the resulting common perspective center
ground
Y_s
X_s
Y_n
O
X_n
45º
X_n
Y_s
Y_n
X_s
Looking along arrow A

FIGURE 2

APPENDIX I

PROOF OF FORMULAE ON PAGE EIGHT

Figure 2 is a perspective view of one of the four constituent cameras of a quadruple camera. The photographic coordinates X_1 and Y_1 relating to the considered ray are supposed to have been measured, and we want to know a set of consistent coordinates X_n, Y_n, Z_n defining a practically equivalent ray centered in C. Z_n is on the axis of the composite system and consequently common to the four partial photographs.

First coordinates transformation:

Rotation around the axis of the partial camera by 45°

$$X_r = \frac{X_1 + Y_1}{\sqrt{2}} \qquad Y_r = \frac{-X_1 + Y_1}{\sqrt{2}} \qquad Z_r = Z_1 = f$$

Second coordinates transformation:

Rotation around an axis passing through C_1 and perpendicular to the plane O_1C_1C

$$X'_s = X_r\cos\gamma - Z_r\sin\gamma$$

$$Y_s = Y_r$$

$$Z_s = Z_r\cos\gamma + X_r\sin\gamma$$

Centering on C instead of C_1:

Similar triangles, the one with $e = CC_1$ as the upper side, the other with $X_s - X'_s$, give

$$\frac{X_s - X'_s}{Z_s} = \frac{e}{H_g}, \text{ hence} \qquad X_s = X'_s + \frac{e}{H_g} Z_s$$

Third coordinates transformation:

Rotation around the axis of composite system by 45° in the contrary sense to first rotation

$$X_n = \frac{X_s - Y_s}{\sqrt{2}} \qquad Y_n = \frac{X_s + Y_s}{\sqrt{2}} \qquad Z_n = Z_s$$

Combining all these equations and setting

$$\frac{\cos\gamma + 1}{2} = A \qquad \frac{\cos\gamma - 1}{2} = B \qquad \frac{\sin\gamma}{\sqrt{2}} = C$$

$$\frac{e}{2\,H_g}\sin\gamma = \delta' \qquad \frac{e}{\sqrt{2}\,H_g}\cos\gamma = \delta''$$

we get the equations of page eight of the paper.

Actually, the equations take the following simplified form in practical application (putting together all the constants):

$$\boxed{\begin{aligned} X_n &= mX_1 + nY_1 - p \\ Y_n &= nX_1 + mY_1 - p \\ Z_n &= q(X_1 + Y_1) + r \end{aligned}}$$

where m, n, p, q, r are all constants

If the traversing instrument in which the transformed photographic coordinates are used is unable to accommodate a varying value for Z_n the set of equations goes over to the following (which indeed implies division):

$$X_n = h\,\frac{mX_1 + nY_1 - p}{q(X_1 + Y_1) + r}$$

$$Y_n = h\,\frac{nX_1 + mY_1 - p}{q(X_1 + Y_1) + r}$$

where h is an arbitrary constant

$$Z_n = h$$

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